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NASA LANGLEY RESEARCH CENTER NATIONAL AERO-SPACE PLANE MISSION SIMULATION PROFILE SETS

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Abstract

To provide information on the potential for long-life service of oxidation-resistant carbon-carbon (ORCC) materials in the National Aero-Space Plane (NASP) airframe environment, NASP ascent, entry, and cruise trajectories were analytically flown at NASA Ames-Dryden on a Government baseline vehicle. Temperature and pressure profiles were generated for 20 vehicle locations. This paper presents orbital (ascent and entry) and cruise profile sets from four selected locations along with the humidity exposure and testing sequences that are being used to evaluate ORCC materials in NASA Langley's Multiparameter Mission Simulator. The four profiles show peak temperatures during the ascent leg of an orbital mission of 2800°, 2500°, 2000° and 1700°F. These profiles bracket conditions where carbon-carbon might be used on the NASP vehicle.

Introduction

Oxidation-resistant carbon–carbon (ORCC) materials are being considered for use in various locations on the National Aero-Space Plane (NASP) vehicle. To provide information on the potential for long-life service of ORCC materials in the NASP airframe environment, oxidation performance evaluations are currently being conducted on three state-of-the-art ORCC composites at NASA Langley Research Center.[1]

Since the airframe environment varies substantially from one location to another over the surface of the vehicle, no single cruise and orbital set of temperature and pressure profiles is adequate to do a complete evaluation. Also, no consistent set of orbital and cruise mission profiles for specific locations on a NASP type vehicle was available for simulation. Thus, in order to perform meaningful ORCC evaluations, multiple mission profile sets were needed. In addition to the service temperature and pressures profiles, ground environment is also important since it is well established that moisture can significantly degrade oxidation protection coating performance[2-5]. This paper presents a series of orbital and cruise missions profile sets along with the humidity exposure and testing sequences that are being used to evaluate ORCC materials in Langley's Multiparameter Mission Simulator.

Profile Generation

NASP ascent, entry, and cruise trajectories were analytically "flown" at NASA Ames-Dryden on a Government baseline vehicle. A simple guidance scheme, developed by the Air Force Flight Test Center, was used to help the pilot maintain the desired dynamic pressure throughout each trajectory. It was based on a schedule of dynamic pressure versus Mach number, and allowed the desired trajectory to be maintained by simple adjusting the vehicle's pitch attitude in response to a queue displayed on the horizontal steering bar. The ascent trajectory was flown with a schedule of varying dynamic pressures, while the entry trajectory was flown at a constant value. Dynamic pressures on the cruise trajectory varied during climb and acceleration but were held constant during cruise, descent, and landing. Further details concerning trajectories and dynamic pressures cannot be given here because of classification restrictions.

The thermal model used was developed in-house for generic hypersonic vehicle simulation[6]. It consisted of two stagnation and eighteen flat-plate points. The stagnation points were the tip of the nose and a wing leading edge. Three-dimensional and two-dimensional flow fields were assumed respectively. There were five flat-plate locations on the lower fuselage centerline, four on a wing underside at various distances from the wing leading edge, and nine more on the upper vehicle surface at the same relative positions. Fuselage plates near the nose were assumed to be deflected slightly from the XY body axis plane while all other plates were assumed parallel to it. Conical flow was not assumed at any flat-plate point. Thermal model inputs included ambient static pressure, ambient air temperature, atmospheric density, angle-of-attack, true airspeed, and Mach number.

Pressures for the two stagnation points were calculated in the thermal model since they were required for the temperature computations. Flat-plate pressures were generated by another Ames-Dryden in-house model which made use of Van Dyke methodology. All plate locations and surface deflections were the same as for the thermal model. Inputs required were ambient static pressure, angle-of-attack, Mach number, and dynamic pressure.

Vehicle Locations Simulated

To span the range of temperature conditions where carbon-carbon might be used, four of the twenty vehicle locations were selected for mission simulation testing of ORCC composites. The four locations were the wing leading edge (L.E.), on the fuselage less than 3 feet from nose, on the fuselage 3 feet from nose, and on the wing 12 feet from L.E. The latter three points were on the lower surfaces of the vehicle. For each vehicle location a profile set consists of both a cruise mission and an orbital mission. Ascent and entry profiles have been combined into a single orbital mission in which the entry portion is started after the ascent leg has cooled down to 550°F. Peak temperatures on the ascent leg of the orbital mission range from a high of 2800°F to a low of 1700°F. Each profile set is designated by its location on the vehicle and its peak ascent temperature. For example, the profiles generated for the wing leading edge are designated Wing L. E. or 2800°F profile set.

Temperature and Pressure Profiles for Wing L.E.

Figure 1 as well as Tables I and II show the temperature and pressure profiles for a point on the wing leading edge. Temperatures peak at 2378°F with an extended period at 2240°F for Mach 14 cruise conditions. The maximum temperature for the ascent portion of the orbital mission is 2795°F. The maximum temperature during the entry leg is 2265°F. Pressures are generally less than 0.04 atmospheres during the heating and cooling portions of both orbital and cruise missions.

Temperature and Pressure Profiles for Fuselage < 3' from Nose

Figure 2 as well as Tables III and IV show the temperature and pressure profiles for a point on the fuselage less than 3 feet from the nose. Temperatures peak at 2012°F with an extended period at 1950°F for Mach 14 cruise conditions. The maximum temperature for the ascent portion of the orbital mission is 2500°F. The maximum temperature during the entry leg is 2160°F. Pressures are generally less than 0.06 atmospheres during the heating and cooling portions of both orbital and cruise missions.

Temperature and Pressure Profiles for Fuselage 3' from Nose

Figure 3 as well as Tables V and VI show the temperature and pressure profiles for a point on the fuselage 3 feet from the nose. Cruise temperatures peak at 1681°F with an extended period at 1650°F. The maximum temperature for the ascent portion of the orbital mission is 1978°F. The maximum temperature during the entry leg is 2160°F. For both missions, pressures are generally less than 0.06 atmospheres. The pressure profiles for this point are identical to the pressure profiles for the point on the fuselage less than 3 feet from the nose.

Temperature and Pressure Profiles for Wing 12' from L.E.

Figure 4 as well as Tables VII and VIII show the temperature and pressure profiles for a point on the wing 12 feet from the leading edge. This point was selected because the cruise profile has an extended period in the 1100°F to 1200°F range, a well-known problem region for ORCC composites since cracks tend to be open but sealants are not fully activated. Cruise conditions peak at 1638°F with an extended period at 1150°F. The maximum temperature for the ascent portion of the orbital mission is 1714°F. The maximum temperature during the entry leg is 1604°F. As with the other vehicle locations, pressures are generally less than 0.04 atmospheres for both orbital and cruise missions.

Testing Procedure

The humidity exposure condition was determined by considering typical humidity conditions at NASA Ames-Dryden Flight Research Facility where the X-30 vehicle will be based. The period of time with the highest absolute humidity was summer nights where the average absolute humidity was 10.8 g/m^3 or a 42 percent relative humidity (RH) at 80°F. To be slightly conservative, an absolute humidity of 12.9 g/m^3, equivalent to 50 percent RH at 80°F, was selected for an exposure condition.

The test sequence used is cruise-humidity-orbit-humidity-cruise-humidity-orbit, etc. Cruise and orbit missions are alternated so 50 percent of total missions simulated are of each type. The test materials are first dried at 250°F in vacuum for 14 hours to establish a baseline dry weight. They are then exposed to humidity for a minimum of 72 hours. After this initial humidity exposure the specimens are cycled through cruise and orbital missions using a dry flowing air atmosphere, one cruise or orbital mission each day, with a 22-hour humidity exposure between each mission. This testing scenario is believed to provide realistic test conditions for the evaluation of candidate ORCC materials.

Summary

NASP ascent, entry, and cruise trajectories were analytically flown at NASA Ames-Dryden on a Government baseline vehicle. Temperature and pressure profiles were generated for 20 vehicle locations. Orbital (ascent and entry) and cruise profile sets from four selected locations along with humidity exposures are currently being used to evaluate ORCC materials in Langley's Multiparameter Mission Simulator. The four profiles show peak temperatures during the ascent leg of an orbital mission of 2800°, 2500°, 2000° and 1700°F. These profiles bracket conditions where carbon-carbon might be used on the NASP vehicle.

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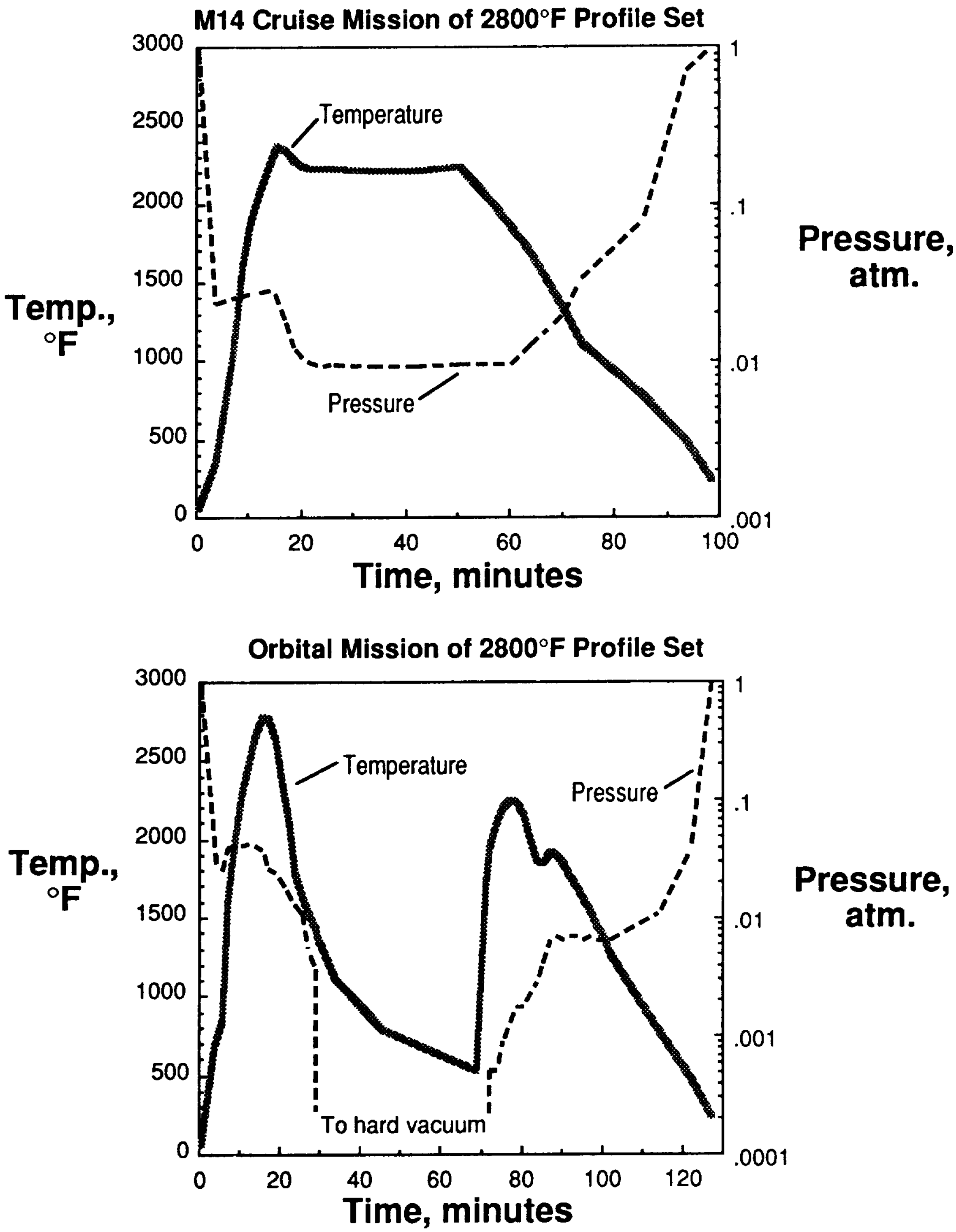


Figure 1. Temperature and pressure profiles for the wing leading edge.

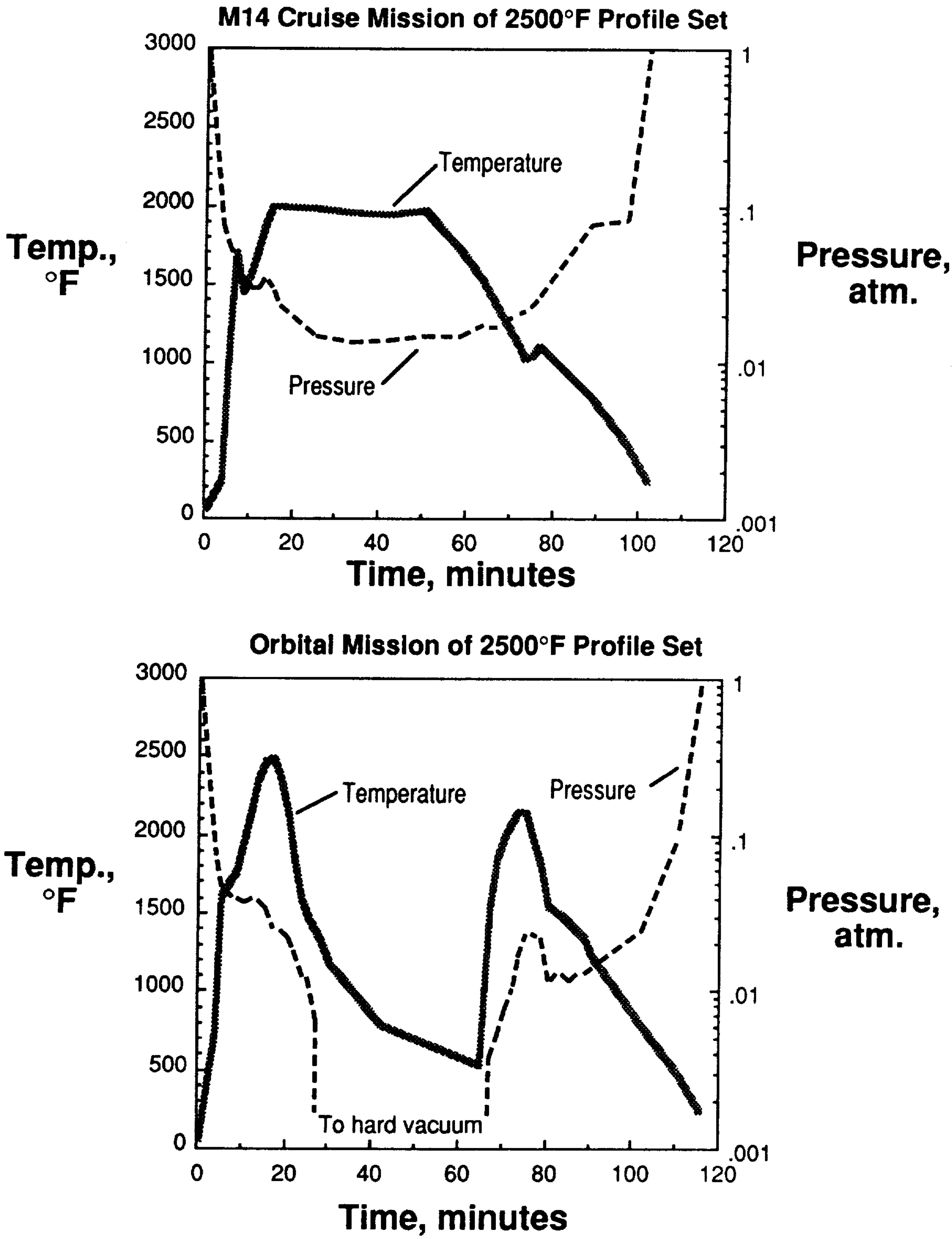
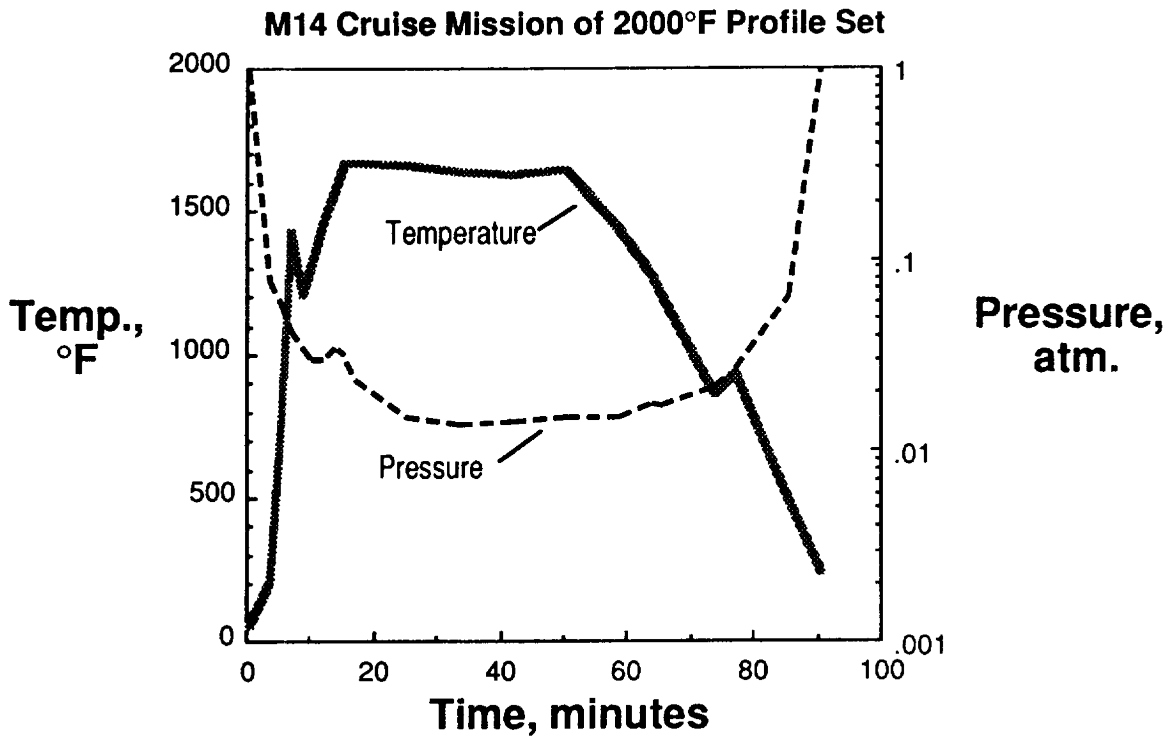


Figure 2. Temperature and pressure profiles for the fuselage <3' from the nose.



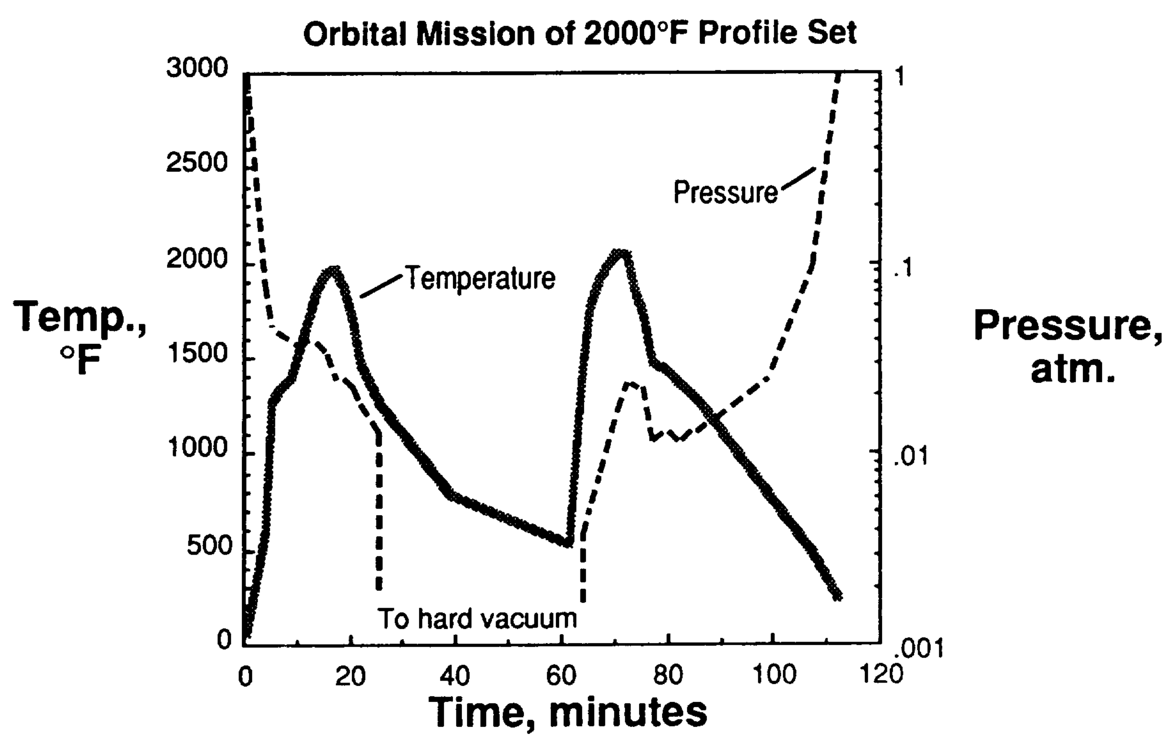
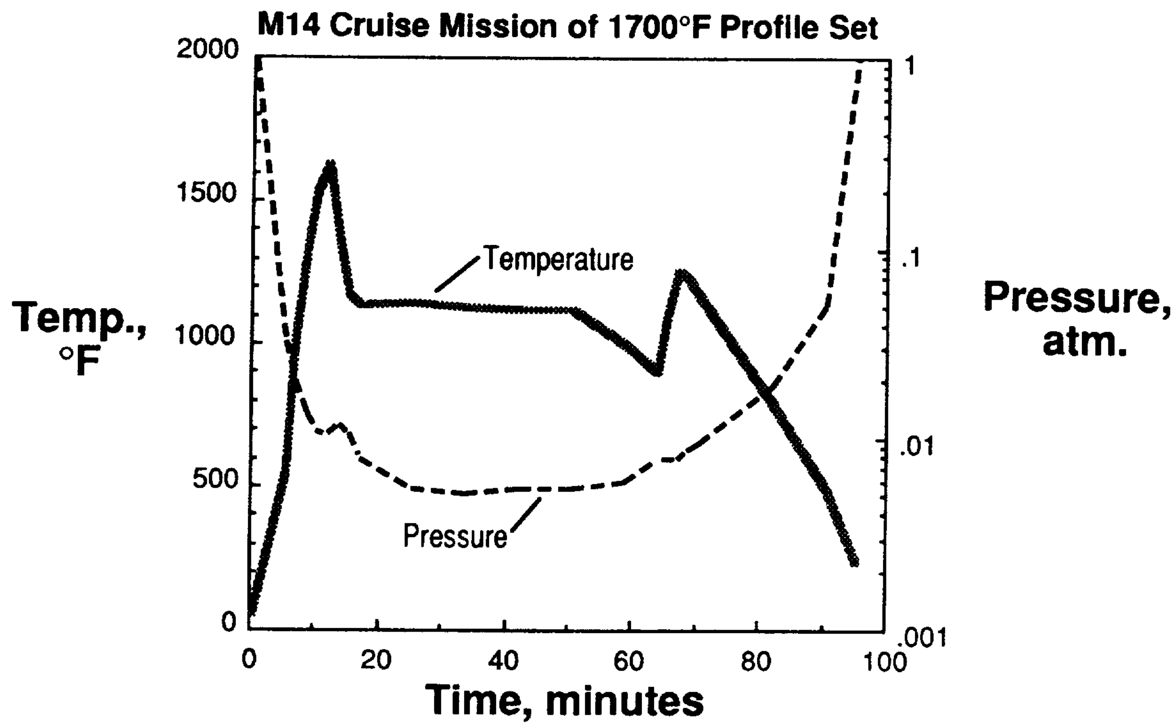


Figure 3. Temperature and pressure profiles for the fuselage 3' from the nose.



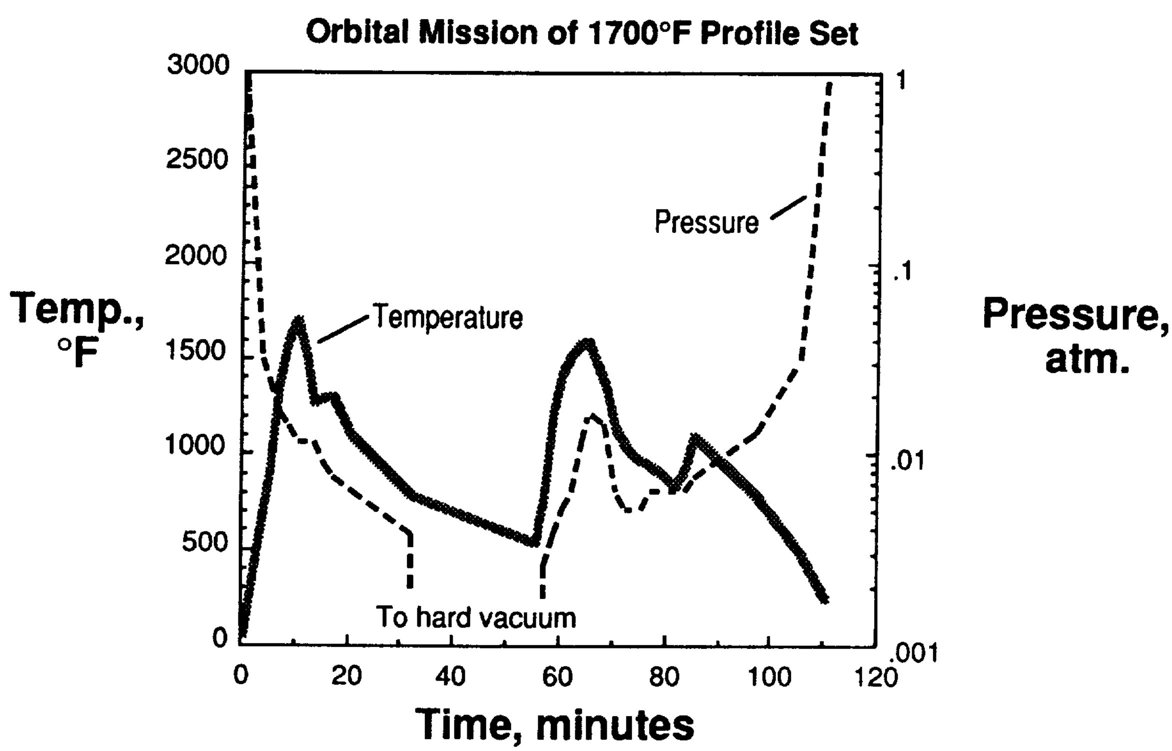


Figure 4. Temperature and pressure profiles for the wing 12' from L.E.

Table I. Tabulated Temperature and Pressure Profiles for the Wing Leading Edge: Cruise Mission of the 2800°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
3:20	360	0.0237
6:40	1056	0.0263
8:20	1604	0.0270
10:00	1893	0.0274
11:40	2097	0.0283
13:20	2259	0.0288
15:00	2378	0.0268
16:40	2344	0.0179
18:20	2290	0.0128
20:00	2251	0.0109
21:40	2241	0.0099
23:20	2235	0.0095
25:00	2242	0.0099
33:20	2229	0.0095
41:40	2231	0.0095
50:00	2253	0.0099
53:20	2130	0.0099
56:40	2009	0.0099
60:00	1866	0.0099
63:20	1701	0.0130
66:40	1523	0.0161
70:00	1334	0.0211
73:20	1120	0.0339
85:00	800	0.0789
93:20	500	0.7132
98:20	250	1.0000

Table II. Tabulated Temperature and Pressure Profiles for the Wing Leading Edge: Orbital Mission of the 2800°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
3:20	700	0.0329
5:00	861	0.0263
6:40	1632	0.0408
8:20	2041	0.0421
10:00	2291	0.0421
11:40	2499	0.0434
13:20	2669	0.0421
15:00	2795	0.0395
16.:40	2788	0.0276
18:20	2650	0.0250
20:00	2400	0.0211
21:40	2100	0.0171
23:20	1800	0.0137
25:00	1650	0.0113
26:40	1550	0.0057
28.:20	1440	0.0038
29:10	1383	Hard vacuum
30:00	1325	Hard vacuum
33:20	1125	Hard vacuum
45:00	800	Hard vacuum
68:20	550	Hard vacuum
70:50	1720	Hard vacuum
71:40	1954	0.0005
73:20	2126	0.0005
75:00	2212	0.0009
76:40	2265	0.0013
78:20	2256	0.0018
80:00	2162	0.0018
81:40	2026	0.0024
83:20	1881	0.0029
85:00	1864	0.0042
86:40	1940	0.0066
88:20	1910	0.0071
90:00	1845	0.0066
91:40	1781	0.0071
93:20	1709	0.0071
95:00	1629	0.0066
96:40	1549	0.0071
98:20	1464	0.0066
100:00	1373	0.0066
101:40	1281	0.0066
113:20	800	0.0111
121:40	500	0.0395
126:40	250	1.0000

Table III. Tabulated Temperature and Pressure Profiles for the Fuselage <3' from the Nose: Cruise Mission of the 2500°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
3:20	257	0.0789
5:00	941	0.0592
6:40	1717	0.0439
8:20	1461	0.0350
10:00	1587	0.0307
11:40	1754	0.0312
13:20	1893	0.0350
15:00	2007	0.0326
16:40	2012	0.0237
25:00	1995	0.0151
33:20	1973	0.0142
41:40	1963	0.0146
50:00	1984	0.0155
58:20	1725	0.0155
63:20	1532	0.0179
65:00	1458	0.0175
66:40	1379	0.0175
68:20	1300	0.0189
70:00	1215	0.0203
71:40	1128	0.0217
73:20	1042	0.0222
75:00	1060	0.0250
76:40	1127	0.0279
88:20	800	0.0789
96:40	500	0.0842
101:40	250	1.0000

Table IV. Tabulated Temperature and Pressure Profiles for the Fuselage <3' from the Nose: Orbital Mission of the 2500°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
3:20	757	0.0789
5:00	1617	0.0487
6:40	1711	0.0434
8:20	1775	0.0408
10:00	1979	0.0382
11:40	2193	0.0408
13:20	2358	0.0395
15:00	2484	0.0355
16:40	2500	0.0263
18:20	2376	0.0250
20:00	2152	0.0224
21:40	1883	0.0184
23:20	1614	0.0132
25:00	1480	0.0118
26:40	1390	0.0066
27:30	1340	Hard vacuum
30:00	1188	Hard vacuum
41:40	800	Hard vacuum
64:10	550	Hard vacuum
65:50	1211	Hard vacuum
66:40	1542	0.0039
68:20	1867	0.0053
70:00	2013	0.0079
71:40	2099	0.0105
73:20	2160	0.0171
75:00	2154	0.0237
76:40	1981	0.0224
78:20	1825	0.0224
80:00	1563	0.0118
81:40	1536	0.0132
83:20	1500	0.0132
85:00	1450	0.0118
86:40	1404	0.0132
88:20	1350	0.0132
90:00	1231	0.0145
101:40	800	0.0250
110:00	500	0.1000
115:00	250	1.0000

Table V. Tabulated Temperature and Pressure Profiles for the Fuselage 3' from the Nose: Cruise Mission of the 2000°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
3:20	215	0.0789
5:00	786	0.0595
6:40	1434	0.0439
8:20	1220	0.0350
10:00	1326	0.0307
11:40	1465	0.0312
13:20	1581	0.0350
15:00	1676	0.0326
16:40	1681	0.0237
25:00	1666	0.0151
33:20	1648	0.0142
41:40	1640	0.0146
50:00	1657	0.0155
58:20	1441	0.0155
63:20	1280	0.0179
65:00	1218	0.0175
73:20	870	0.0222
76:40	942	0.0279
85:00	500	0.0658
90:00	250	1.0000

Table VI. Tabulated Temperature and Pressure Profiles for the Fuselage 3' from the Nose: Orbital Mission of the 2000°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
3:20	599	0.0789
5:00	1280	0.0487
6:40	1354	0.0434
8:20	1405	0.0408
10:00	1566	0.0382
11:40	1735	0.0408
13:20	1866	0.0395
15:00	1965	0.0355
16:40	1978	0.0263
18:20	1880	0.0250
20:00	1703	0.0224
21:40	1490	0.0184
25:00	1277	0.0132
25:50	1247	Hard vacuum
38:20	800	Hard vacuum
60:50	550	Hard vacuum
62:30	1165	Hard vacuum
63:20	1473	0.0039
65:00	1783	0.0053
66:40	1923	0.0079
68:20	2005	0.0105
70:00	2063	0.0171
71:40	2057	0.0237
73:20	1892	0.0224
75:00	1743	0.0224
76:40	1493	0.0118
78:20	1467	0.0132
80:00	1433	0.0132
81:40	1385	0.0118
83:20	1341	0.0132
85:00	1290	0.0132
86:40	1236	0.0145
98:20	800	0.0250
106:40	500	0.1000
111:40	250	1.0000

Table VII. Tabulated Temperature and Pressure Profiles for the Wing 12' from the Leading Edge: Cruise Mission of the 1700°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
5:00	556	0.0336
6:40	1035	0.0208
8:20	1355	0.0142
10:00	1542	0.0113
11:40	1638	0.0109
13:20	1352	0.0122
15:00	1174	0.0109
16:40	1142	0.0080
25:00	1153	0.0057
33:20	1140	0.0053
41:40	1130	0.0057
50:00	1130	0.0057
58:20	1011	0.0062
63:20	911	0.0080
65:00	1100	0.0080
66:40	1264	0.0080
68:20	1238	0.0089
70:00	1179	0.0099
81:40	800	0.0197
90:00	500	0.0526
95:00	250	1.0000

Table VIII. Tabulated Temperature and Pressure Profiles for the Wing 12' from the Leading Edge: Orbital Mission of the 1700°F Profile Set.

Time, min:sec	Temperature, °F	Pressure, atm.
0:00	68	1.0000
3:20	700	0.0329
5:00	913	0.0250
6:40	1385	0.0171
8:20	1611	0.0145
10:00	1714	0.0118
11:40	1520	0.0118
13:20	1284	0.0118
15:00	1301	0.0092
16:40	1319	0.0079
20:00	1115	0.0066
31:40	800	0.0039
32:30	789	Hard vacuum
55:00	550	Hard vacuum
55:50	660	Hard vacuum
56:40	771	0.0026
58:20	1230	0.0039
60:00	1445	0.0053
61:40	1541	0.0066
63:20	1594	0.0118
65:00	1604	0.0171
66:40	1489	0.0158
68:20	1367	0.0145
70:00	1146	0.0066
71:40	1064	0.0053
73:20	1019	0.0053
75:00	981	0.0053
76:40	950	0.0066
78:20	917	0.0066
80:00	883	0.0066
81:40	844	0.0066
83:20	934	0.0066
85:00	1115	0.0079
96.:40	800	0.0132
105:00	500	0.0329
110:00	250	1.0000

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15. Supplementary Notes

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16. Abstract

To provide information on the potential for long-life service of oxidation-resistant carbon-carbon (ORCC) materials in the National Aero-Space Plane (NASP) airframe environment, NASP ascent, entry, and cruise trajectories were analytically flown at NASA Ames-Dryden on a Government baseline vehicle. Temperature and pressure profiles were generated for 20 vehicle locations. This paper presents orbital (ascent and entry) and cruise profile sets from four locations along with the humidity exposure and testing sequences that are being used to evaluate ORCC materials in NASA Langley's Multiparameter Mission Simulator. The four profiles show peak temperatures during the ascent leg of an orbital mission of 2800°, 2500°, 2000°, and 1700°F. These profiles bracket conditions where carbon-carbon might be used on the NASP vehicle.

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